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## IMPROVING THE LOAD CARRYING CAPACITIES OF SUBGRADES

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# IMPROVING THE LOAD CARRYING CAPACITIES OF SUBGRADES

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The rapid increase in wheel loads and tire pressures have stimulated the development of improved techniques and equipment for strengthening subgrades in order that pavements can be laid with reasonable assurance against failure.

In the highway field there has been a phenomenal increase in axle loads and of equal importance the volume of truck traffic has increased enormously, thus bringing the repetitive load problem to the fore. Tire pressures have remained fairly constant at 90 pounds per square inch.

Airplane design has advanced rapidly until today a wheel assemblage carrying 150,000 pounds is utilized for the heavier planes; and tire pressures have increased to the point where 250 pounds per square inch is in immediate prospect.

Thus, engineers are faced with heavier mass loads, often applied repetitively many times daily, and with loads of high unit intensity. These conditions require subgrades of high stability under all weather conditions.

In New Jersey, the main highways carry over 5,000 heavy trucks per day and axle loads in excess of 40,000 pounds have been weighed. A significant portion of the daily truck traffic has axle loads in excess of 30,000 pounds. The heavy repetitive load engenders a pumping action that flushes water in the subgrade to the surface causing a "quaking" which will destroy all but the heaviest pavements whether of the rigid or the flexible type. Observations show that the damage curve rises fairly uniformly up to 200 applications per day, then turns upward and after 300 applications it rises with great rapidity. Other States are experiencing similar problems in varying degree depending on load laws and the volume of heavy traffic.

For more than 100 years it has been recognized that subgrades must be well drained and kept dry regardless of weather conditions if they are to be expected to carry heavy wheel loads, particularly when applied frequently. The heavier and more frequent the load the greater the depth stability is required in order to lower the unit stress to the capacity of the saturated soil. In climates subjected to freezing and thawing, the water table should be below frost penetration for all but the most porous soils. (Perma-frost conditions are not treated herein since they present specialized problems.)

Within the past thirty years the principles of subgrade drainage have been neglected in many instances particularly in the earlier years when loads were light and infrequent; and more lately, it has been considered

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1. Chf. Eng., New Jersey Turnpike Authority, New Brunswick, N. J. Delivered at the American Society of Civil Engineers Convention, Chicago, September 3, 1952.

that heavy duty pavement could bridge and overcome deficiencies in the subgrade. As a consequence, engineers in some degree lost sight of the advantages and necessity of providing positive subgrade drainage. Since World War II, with the upsurge in the volume of weight traffic, engineering thinking has returned to first principles and greater attention is being paid to drainage.

Soils engineering has classified the various types of soils and precise information is now available on the characteristics of the various classes of soils and which types are suited for use in embankments and subgrades.

Thus the engineering tools are available for the adequate economic design of subgrades used in conjunction with a selected pavement design to meet the requirements of loading, frequency, soil and climatic conditions.

Designs are utilized which provide the greatest overall economy of pavement and subgrade taking into consideration ultimate life and upkeep cost. Under conditions prevailing in the United States, design must take into account the use of materials and methods which are suitable of placement by large capacity heavy duty, fast moving machines incorporating low cost local materials to the maximum consistent with economy.

Illustrative of recent trends, the designs and methods utilized on a large eastern highway project will be reviewed.

The project is located in a humid area, with an average annual rainfall of 45.86 inches, maximum summer temperature ranging up to 100° and winter temperature below zero fahrenheit, with frost penetration down to a depth of four feet. The ground water table is quite high throughout the length of the project. The pavement was designed for 36,000 pound axle loads with unlimited repetitions and tire pressure of 90 pounds per square inch.

Design proceeded on the basis that the ground water table must be permanently lowered for a depth of four feet below the surface of the pavement, that unsuitable soils must be removed from within the roadway area, that surface soils would be stripped before placing fills, that cuts with unstable soils would be undergraded and that all fills and cuts within the roadway would be consolidated to specified densities at optimum moisture.

This provided a stable foundation on which to place sub-base and subgrade layers composed of selected granular, frost-resistant, free draining materials consolidated to specified densities at optimum moisture.

Grading specifications required the cutting, removing and cleaning up of all timber, brush, grain, grass, weeds, stumps and rubbish for the full width of cuts and embankments. Grubbing was required within all excavated areas for a depth of 12 inches below excavation lines and in embankment areas to 12 inches below the original ground.

After clearing, grubbing and stripping, the ground surface for a depth of 12 inches upon which fills five feet or more in depth below finished pavement were to be placed were compacted to 90% density (AASHO Modified) when in cultivated areas, and for fills less than 5 feet deep all ground areas were compacted to 90% density 12 inches deep. Cuts were compacted to 90% density between ditch lines for a depth of 12 inches below template grade which was the surface on which the layers of subgrade materials were placed as hereinafter described.

Embankment material was deposited in layers not to exceed 6 inches in thickness and compacted to 90% density, except the material within 12 inches of template grade was compacted to 95% density. Material classified as A-6 or A-7, Bureau of Public Roads classification, was not permitted within vertical plans through the top of embankment slopes.

These requirements for excavation and embankment construction to template grade were calculated to provide a tested, stable, compacted foundation of suitable soil materials on which to place the special sub-grade materials. See Fig. 1.

The special sub-grade was subdivided into Grade A and Grade B, the latter being placed first on the prepared template grade. This frost resistant granular material, 12 inches thick, was required to have a plasticity index of not more than 6 and so graded that no more than 10% passed a 200 mesh sieve. It was required to have a California Bearing Ratio (CBR) of not less than 15%, when compacted at 100% of maximum density. The bottom of this material was slightly above the elevation of the side ditches. Grade A material, 16 inches thick, placed on top of Grade B was also a pervious, free draining, frost resistant material classified as A-3, by BPR, with a plasticity index of not more than 3 and graded so that no more than 6% passed a 200 mesh sieve. When tested for bearing it had a CBR of not less than 20% when compacted to 100% of maximum density.

Frost-resistant material was defined as being a material with not more than 10% passing a 200 mesh sieve and not more than 5% of its particles less than 0.02 millimeters in size.

A and B material was placed in 6-inch layers and at optimum moisture compacted to 95% (AASHO Modified) maximum density.

This then was the foundation on which the subbase material and paving layers were placed. The side ditches, four feet deep below shoulder elevation, intercept surface and subsurface water flowing toward the roadway while the pervious A and B material, of low capillarity, permits water which might flow upward beneath the roadways to percolate out laterally to the side ditches. In addition, many thousands of feet of pipe underdrainage were provided where wet spots were encountered, in clay formations, at sags in the grade line and other locations where additional sub-surface drainage was required.

The subbase material consisting of 6-1/2 inches of gravel or broken stone (maximum size 3 inches with not more than 5% passing the 200 mesh sieve) compacted to 95% density was placed on the foundation after it had been reshaped by "boxing out" to the pavement cross-section. After boxing out and before placing the subbase, the foundation was again compacted at optimum moisture to 95% density and pre-stressed by four passes (producing two complete coverages) of rubber tired rollers having a tire load of not less than 25,000 pounds. The recompaction of the foundation was not permitted more than 48 hours before placing subbase material and was considered necessary because it had lain open through the winter and had been subjected to frost action and heavy hauling, causing loosening of the upper portion.

The subbase material was surmounted by two layers of penetration macadam and three layers of hot mix asphaltic concrete. Before the

hot mix was placed the surface of the macadam was, in addition to the standard rolling, subjected to four passes, (providing two complete coverages) of rubber tired rollers having a wheel load of not less than 25,000 pounds.

This recitation of the make-up of the subgrade and associated drainage features of this project illustrates the trend in providing well-drained, high load carrying foundations and subgrades for modern pavements. The development of rapid-moving, heavy, mechanized construction equipment has made this development economically possible.

During the construction period of the project a number of practical observations were made which may be of interest. First, the design called for template grade and each layer of the A and B material to be sloped downward from the center line toward the side ditches for the purpose of shedding rainfall to the ditches and from thence to suitable outlets. Two contradictory things happened. In spite of the slope and due to the porosity and the small sized gradation of the Grade A and B materials a considerable amount of rain water penetrated through to the underlying soil layers and where such soil was partly composed of clayey or silty material, these underlying soils were softened and caused instability to depths up to 7 feet below the surface of the pavement. On the other hand, in many areas a considerable amount of rain water did run off and washed granular material into the side ditches. It may be argued that these problems could be overcome by waterproofing the surface as a temporary measure until the pavement is placed. However, heavy hauling would have quickly destroyed a thin waterproofing film and a thicker treatment would not only have been expensive, but would have introduced difficulties when the foundation was "boxed out" for the subgrade material and pavement layers. This is not a serious problem, since it is confined to the construction period only, but it is worthy of consideration where foundations are constructed of finely graded granular materials such as are encountered along the coastal areas of the United States. These sands are not only fine grained, but also are of such gradation that they will consolidate so densely that porosity is reduced. Tests made show that, when consolidated to 100% of density, water will flow through these sands only at a rate of 0.2 foot to 1.00 foot per day.

This means that water will percolate downward and reach the underlying soil long before it can travel laterally the sixty feet required to reach the side ditch.

It had been thought that the use of heavy pneumatic wheels for consolidating and pretesting, without regard to tire pressure would uncover all weak and unstable areas in the foundation. It was found that unstable areas could indeed be detected provided an inspector continuously walked behind the pneumatic rollers and immediately observed the minute traverse cracks that indicated sub-surface instability. These small cracks disappeared shortly after the passage of the roller. In a number of instances the cracks went unobserved and the subgrade material was placed and consolidated. The contractor then operated a fleet of trucks with 90 pound tires hauling stone over the grade for the macadam courses. This resulted in a large number of repetitions causing instability in the weak areas and the unstable material had to be dug out and

replaced. At several locations, instability developed after the top course of penetration macadam had been placed and in a few cases after the hot mix asphaltic concrete had been laid. This experience indicates that consideration should be given to utilizing high tire pressures on pneumatic tire rollers for consolidation.

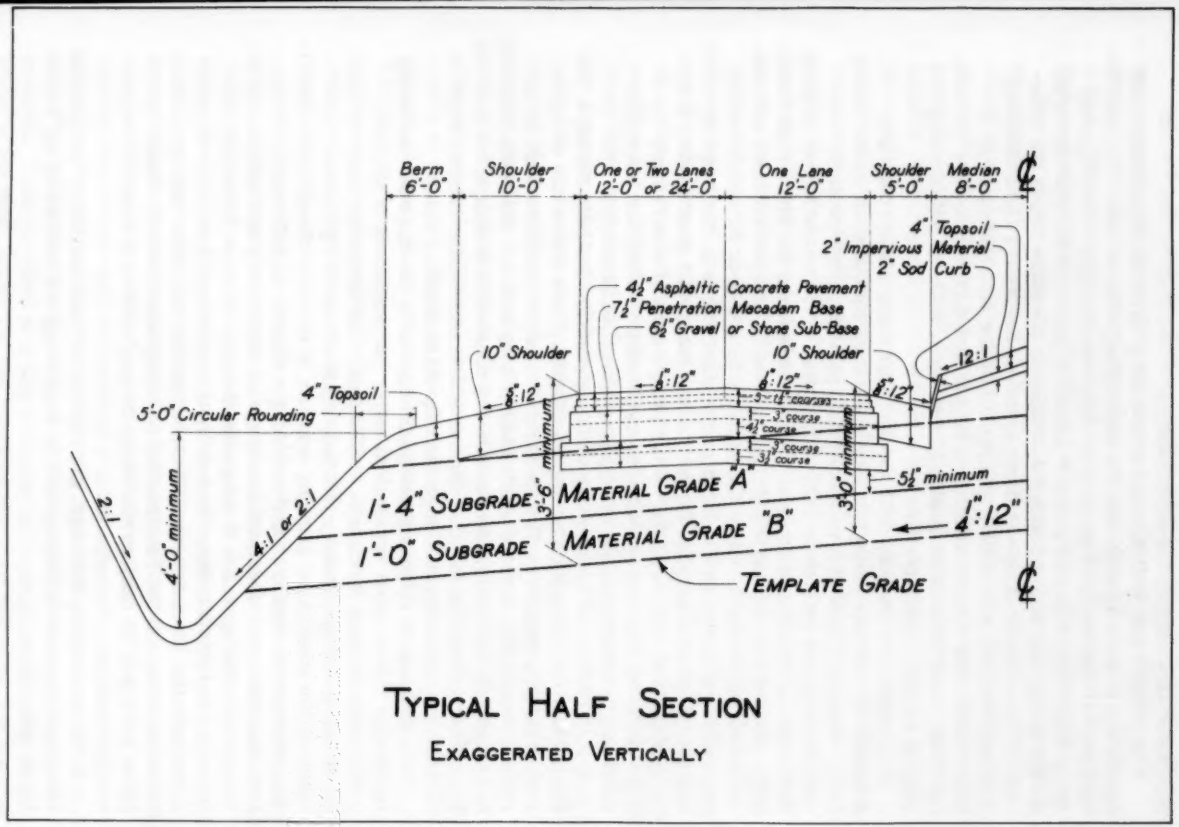
It is evident that well drained stable subgrades and foundations are necessary to such a depth that the underlying soil can carry the distributed load at the required number of daily repetitions. Where ground water is present this will require a determination of the load carrying ability of the soil in a saturated condition at the plane below the influence of the underdrainage or ditch system. Eventually the underlying soil may become sufficiently compacted by the constant passage of heavy loads that excess water may be precluded from entering the soil, but in the meantime if the design is deficient, failures will develop requiring repairs under traffic.

Engineers are familiar with the fact that many older roads constructed of granular materials over the years successfully carry heavy loads when surfaced with relatively thin pavement, particularly when well drained and located on favorable soils. Some roads in this country have been in continuous use and under maintenance for more than a century. During this period traffic has constantly hammered down and consolidated the roadbed. Often the road metal has been driven down into the soil several feet and in the process weak areas in the subgrade were dug out by the maintenance forces and replaced with good quality granular material of high stability. After many years of this "repair-as-it-fails" process under many weather cycles the roadbed has been stabilized and becomes capable of carrying heavy loads safely.

If it is desired to accomplish ultimate stability initially during a relatively short construction period, stable sub grade materials of known load carrying, water reaction and frost resistent qualities must be utilized to the depths required by the underlying soil and the loads expected to be carried; and compacted with heavy construction equipment in order to achieve a stability in a few months which may take a century under a "fill-in-the-weak-places" program. Speed demands a price.

The problem of subgrade design is economic, the engineer selecting the design that is most economical under job conditions of climate, availability of local materials, traffic loads and frequency; and suitability of construction by heavy fast moving mechanical equipment. Because of the absence or growing scarcity of suitable cheap local materials, widespread research is developing a number of interesting processes, materials and chemical adaptions for stabilizing soil which may affect greatly the approach to subgrade design. Cement, bitumins, lime, fly ash, calcium chloride, chrome-lignin, sodium silicate are all under investigation. More research, development by material and equipment, manufactures, and the construction of test projects are in order before those tools will be fully available to the engineer on a competitive economic basis.

In the meantime, drainage, granular materials and heavy compaction equipment remain as the bulwark in improving the load carrying capacity of subgrades.




TYPICAL HALF SECTION

EXAGGERATED VERTICALLY

Fig. 1.